Ref: 57472 / 3

APPLICATION FOR UNITED STATES LETTERS PATENT

LOUDSPEAKER

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT I,

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having an address at 309 Robina Avenue, Toronto, Ontario, Canada, M6C 3Z2

have invented a: **LOUDSPEAKER**

of which the following is a specification.

20603075.1

LOUDSPEAKER

Field of Invention

This invention relates generally to the field of loud speakers.

Background Art

A typical loudspeaker assembly for low to mid-range audible sound reproduction, that is, a bass speaker, or a "woofer", has a magnetic sandwich assembly. The core of the sandwich is typically, an annular magnet, although square or rectangular open center magnets are also known. A backplate, typically circular, is mounted to one annular face of the magnet, and has an outside diameter similar to, the outside diameter of the annular magnet. An annular top plate is mounted to the other face of the magnet. The top plate has an outside diameter similar to the backplate, and an inside diameter less than the inner diameter of the annular magnet. The magnet, the backplate, and the top plate are concentrically mounted about a central axis perpendicular to the annular magnet. The polarity of the magnet is such that the annular top and bottom faces are opposite poles.

In general, the magnet sandwich assembly has a central post, sometimes called a pole piece, a T-yoke, or a core. The pole piece is mounted along the central axis of the magnetic assembly to extend from the backplate toward the top plate. The end of the pole-piece standing furthest away from the backplate usually sits adjacent the inner annular edge or face of the top plate. A small radial gap is left between the top plate and the end of the pole piece. Inasmuch as the top plate, the backplate, and the pole-piece are typically made of ferromagnetic materials, or materials of high magnetic permeability, a magnetic flux field is established by the magnet across the small gap. Thus the magnetic flux path lies completely in materials of relatively high magnetic permeability except for the gas, typically air, in the gap between the inner edge of the annular member and the central post.

A voice coil is suspended to ride in the small gap, which is the location of maximum magnetic flux density. The voice coil can reciprocate linearly relative to the pole piece, and, in so doing, the turns of the coil traverse the field of the magnet. The voice coil is suspended from a resilient suspension, usually in the form of a moving diaphragm assembly mounted on springs. The diaphragm assembly usually has a membrane element that has the shape of a truncated section of a cone, with a dust cap membrane extending across a narrower part of the section. The lead wires

for the coil are usually, though not always, mounted to the cone, typically with glue, and the cone and the voice coil are constrained to move together.

Loudspeaker performance reflects design compromises in the desired power output, the choice of magnet, the choice of coil, the nature of the resilient mounting, the entrapment of air in the assembly, and the size and shape of the cabinetry placed about the loudspeaker itself. A loudspeaker will tend to have a chosen desired operating bandwidth. In general, when operated outside the design bandwidth the speaker is more likely to exhibit non-linear performance, and more likely to exhibit undesirable, or less than optimal, impedance characteristics, and may tend to be more prone to failure.

In operation, the varying electrical current in the voice coil will tend to cause the voice coil to become warm. The heating of the coil is known, and one design consideration is the anticipated operating temperature. When the coil becomes warm, the adjacent metal structure also becomes warm, though generally to a lesser degree. The electrical resistance of copper wire increases with increasing temperature. Inasmuch as the power output of a speaker varies inversely as the resistance of the voice coil, an increase in the temperature of the coil will tend to reduce the current in the coil, and reduce the output power. As a consequence, it is advantageous to keep the voice coil relatively cool, if possible. If the coil is operated too vigorously, its performance will deteriorate, and may ultimately fail. Voice coils of aluminium wire are less likely then copper coils to have a general rise in impedance with increasing power, but also have a tendency to fail with increasing temperature.

In the past, a common solution to the problem of increased resistance due to coil warming has been to choose a larger, heavier speaker to give a higher output power level. A larger voice coil, magnetic assembly, or both, will usually be capable of producing the same power output as a smaller one but with a lower temperature rise, and less deterioration in performance. To maintain the same specified ratio of output to losses, Q_{es} , and therefore Qt_s , it would be customary to increase both the size of the magnet and the size of the coil. It would be advantageous to reduce the operating temperature of the voice coil to permit a smaller motor, {that is, a coil and magnet assembly), to be used at higher power levels, rather than having to adopt a bigger, heavier, and possibly more expensive, unit.

At present, it is not uncommon for the pole piece of a woofer to be hollow, and for the back plate to have a central opening. When the diaphragm moves, the air pocket beneath the dust cover membrane then has an outlet to ambient through the hollow pole piece and through the backplate, so pressure variation in the pocket is reduced. One attempt to use the motion of the air displaced by the dust cover dome to enhance cooling is shown in U.S. Patent 5,042,072 of Button, issued August 20, 1991. Button forms three peripheral grooves in the outer face of the pole piece. These channels vent through the backplate. The usually open hollow core of the pole-piece is blocked such that air is forced to move in or out through the three channels. Inasmuch as the radially outer portion of the channels is bounded by the inner face of the voice coil, Button indicates that portions of the voice coil are cooled by forcing air displaced by the dome through the channels next to the voice coil.

U.S. Patent 5,357,586 of Nordschow and Wright, issued October 18, 1994. It shows a speaker that has radial perforations in the voice coil former at a level above the voice coil. A vane, or aerodynamically shaped body, is mounted within the hollow core of the pole-piece. Air flows more easily past the aerodynamically shaped body in one direction than the other, such that reciprocation of the diaphragm will tend to cause a flow of air through the assembly between the perforations and the opening in the backplate, with a cooling effect.

U.S. Patent 5,497,428 of Rojas issued March 5, 1996. It shows a loudspeaker assembly with channels formed in the external periphery of the pole-piece adjacent to the voice coil. These channels vent into the hollow central core of the pole piece, which, as is customary, is open through the backplate to ambient. The top end of the pole piece is blocked by a generally conical part, such that the air is forced to flow through the channels.

Another noted phenomenon of existing loudspeakers in which the backplate of the speaker is a closed plate, is that the reciprocation of the diaphragm assembly, as in a closed back mid-range to high audible frequency unit, or tweeter, will tend to compress or expand, the air trapped within the loudspeaker casing itself. Where the entrapped volume is small, the effect can be quite pronounced. It is desirable in such instances to increase the internal trapped volume so that the volume displaced by operation of the speaker diaphragm is small relative to the trapped volume, with a consequent lessening of the pressure fluctuations in the entrapped gas. It will be

apparent that compression of the entrapped gas will tend to oppose the motion of the speaker, and may complicate it still more if there is a dynamic resonance problem. A known method of reducing the magnitude of this phenomenon is to provide a larger backshell or housing. This is generally not desirable because it increases the size of the loudspeaker unit for the purpose of enclosing air. It would be advantageous to increase the volume of the entrapped air without having to increase the physical size of the loudspeaker envelope.

U.S. Patent 5,335,287 of Athanas, issued August 2, 1994 relates to a loudspeaker employing a magnetic liquid suspension for locating the voice coil in the gap. According to Athanas, one problem of magnetic liquid voice coils is that the liquid has a tendency to be blown, or drawn, out of the magnetic gap. In Athanas' view this was because the oscillatory motion of the voice coil produces momentary changes in the atmosphere near the end of the pole piece, and in the annular chamber surrounding the pole piece. The loudspeaker shown by Athanas has not only a port through the back plate to vent the hollow core of the pole piece, but also additional vents formed through the backplate to vent the annular chamber formed between the pole piece and the magnet. This is thought to reduce the tendency of the air compressed in the annular chamber from pushing the liquid out of the gap.

<u>Summary of the Invention</u>

In one aspect of the invention there is a magnetically permeable plate for use as the front plate of a magnetic flux path assembly of a loudspeaker. The loudspeaker has a diaphragm driven by a voice coil. The magnetic flux assembly has a pole piece, a magnet, and a magnetic flux path between one pole of the magnet and the pole piece. The plate has an opening defined therein sized to fit about the pole piece and to co-operate with the pole piece to define a gap for accommodating movement of the voice coil therebetween. The top plate has venting defined therein to permit fluid communication through the plate external to the voice coil.

In an additional feature of that aspect of the invention the plate has an outer periphery, an inner periphery defining the opening, and the venting is segregated from the inner periphery. In another additional feature of that aspect of the invention the plate has the form of a disc in which the inner and outer peripheries are circular and concentric. In still another additional feature of that aspect of the invention the

venting includes an array of apertures spaced outwardly from, and having a pitch circle concentric with, the inner periphery. In a further additional feature of that aspect of the invention the apertures are circular. In a still further additional feature of that aspect of the invention the opening has a nominal periphery and the venting includes at least one rebate let into the nominal periphery. In a yet further additional feature of that aspect of the invention the opening has a crenellated profile.

In another aspect of the invention, there is a magnetic flux path assembly for a loudspeaker having a diaphragm, a voice coil for driving the diaphragm and a diaphragm dust cap cavity defined therewithin. The magnetic flux path assembly has a pole piece, an opposed member placed in spaced relationship from the pole piece to define a gap for accommodating reciprocation of the voice coil, and at least one intermediate member mounted to maintain the position of the pole piece and the opposed member relative to each other. The pole piece, the intermediate member, and the opposed member co-operate to form a continuous path of higher magnetic permeability than the gap. At least one of the pole piece, the at least one intermediate member, and the opposed member includes a magnet for establishing a magnetic flux in the magnetic flux path assembly and across the gap. The magnetic flux path assembly has an airflow path defined therein extending between the dust cap cavity and external ambient, for permitting displacement of air between the cavity and external ambient. At least a portion of the airflow path is defined in the opposed member external to the gap, whereby displacement of air by the dust cap member causes motion of air in the portion of the airflow path in the opposed member to encourage cooling of the opposed member.

In an additional feature of that aspect of the invention, the opposed member is a plate having an outer periphery. A closed inner periphery defines an opening extending about the pole piece. The gap lies between the periphery and the pole piece. A portion of the airflow path is formed in the plate and is segregated from the opening. In another additional feature of that aspect of the invention, the plate has the form of a disc in which the inner and outer peripheries are circular and concentric. In still another additional feature of that aspect of the invention, the portion of the airflow path formed in the plate includes an array of apertures spaced outwardly from, and having a pitch circle concentric with, the inner periphery.

In still yet another additional feature of that aspect of the invention, the opposed member is a plate having an outer periphery. A closed inner periphery defines an opening extending about the pole piece. The gap lies between the periphery and the pole piece. At least one portion of the inner periphery defines the gap, and another portion of the periphery defines the portion of the airflow path defined in the opposed member.

In a further additional feature of that aspect of the invention, the magnetic flux path assembly has an axis parallel to the direction of reciprocation of the voice coil. The pole piece has a distal region thereof distant from the rigid member. The distal region has the form of a body of revolution concentric with the axis. The opposed member is a plate having a closed inner periphery extending about the pole piece distal region. The inner periphery has at least one sector of a circular arc concentric with the distal region. The sector has a radius. The inner periphery also includes at least one relief defined in the plate. The relief extends radially outward relative to the radius of the sector. The gap is defined between the sector and the pole piece. The relief defines at least a part of the portion of the airflow path defined in the opposed member.

In yet a further additional feature of that aspect of the invention, the assembly has a central axis. The pole piece has a round portion. The opposed member is a disc having an outer periphery and a closed inner periphery extending about the round portion of the pole piece. The inner periphery has a plurality of sectors of a circular arc having a common radius, and a plurality of reliefs defined in the disc extending radially outward relative to the radius of the sectors. The round portion of the pole piece and the sectors are concentric about the axis. The gap is defined between the sectors and the pole piece, and the portion of the airflow path being defined, at least in part, by the reliefs. The reliefs and the sectors are arranged in a symmetrical array about the axis. In still yet a further additional feature of that aspect of the invention, the pole piece includes a the magnet.

In an additional feature of that aspect of the invention, for a loudspeaker having a round cylindrical voice coil for driving the diaphragm along an axis of reciprocation, and supporting structure for mounting the diaphragm to the flux path assembly, the opposed piece is a first plate mounted to one portion of the intermediate member. The intermediate member includes structure extending away from the first

plate, and a second plate mounted to the structure parallel to the first plate. The first plate has an inner periphery defining an opening, and the pole piece is mounted to extend at least partially from the second plate toward the first plate. The pole piece and the inner periphery co-operate to define a gap for accommodating reciprocating motion of the voice coil with the pole piece located internally with respect to the voice coil. The magnetic flux path assembly has an enclosed space defined between the pole piece, the structure, and the pair of plates. The pole piece has a first passageway defined therein to permit fluid communication between the cavity and the space. The first plate has venting defined therein to permit fluid communication between the space and external ambient.

In another additional feature of that aspect of the invention, the magnet has a circular cross-section perpendicular to the axis and a distal end extending away from the intermediate member. The pole piece has an end cap surmounting the distal end of the magnet. The end cap has a circular cross-section perpendicular to the axis and has a larger diameter than the distal end of the magnet. The distal end member has passages defined therethrough permitting, in use, fluid communication between the cavity and the space. In still another additional feature of that aspect of the invention, the end cap has an external periphery and the passages are channels formed in the periphery. In yet another additional feature of that aspect of the invention, the end cap has a round circular periphery and the passages are apertures formed through the end cap.

In another additional feature of that aspect of the invention, the venting includes flow director elements for enhancing convective heat transfer from the voice coil. In still another additional feature of that aspect of the invention, the venting includes at least one deflector for directing airflow toward the voice coil.

In yet still another additional feature of that aspect of the invention, the venting includes at least one tube having an outlet oriented to urge air displaced through the tube toward a portion of the voice coil.

In a further additional feature of that aspect of the invention, the tube is a bent tube having a pair of ends. One of the ends is oriented to urge air displaced through the tube toward a portion of the voice coil during flow in one direction. The other is

oriented to urge air displaced through the tube toward a portion of the voice coil during flow in the other direction.

In still a further additional feature of that aspect of the invention, for a voice coil having an external surface, the opposed member is a plate having a closed inner periphery defining an opening extending about the pole piece. The gap is defined between at least one portion of the periphery and the pole piece. The venting is defined by another portion of the periphery in the nature of a relief defined in the plate. The relief extends radially away from the pole piece and permits air to traverse the plate. The assembly has at least one air guide mounted to the plate to direct air flowing through the relief along at least a portion of the external surface of the voice coil.

In yet a further additional feature of that aspect of the invention, the assembly includes an array of the reliefs and a corresponding array of air guides spaced about the axis. In still yet a further additional feature of that aspect of the invention, the assembly has an internal enclosed space, and the venting permits air flow between the internal enclosed space and external ambient. The assembly has associated with at least one relief, an air guide mounted to extend from one side of the plate, and another air guide mounted to extend away from the other side of the plate. In yet another further additional feature of that aspect of the invention, the air guide is a channel having an open longitudinal side facing the voice coil, and the channel extends parallel to the axis.

In another aspect of the invention, there is a magnetic flux path assembly for a loudspeaker having a diaphragm, and a round cylindrical voice coil for driving the diaphragm along an axis of reciprocation. The voice coil and a diaphragm dust cap cavity are defined there within, and supporting structure for mounting the diaphragm to the flux path assembly. The magnetic flux path assembly has an annular magnet having a pair of annular faces and an inner wall defining an eye therethrough. It has a first plate mounted to one annular face of the magnet, a second plate mounted to the other annular face of the magnet, and a pole piece. The first plate has an inner periphery defining an opening, and the pole piece is mounted to extend at least partially through the eye from the second plate toward the first plate. The pole piece and the inner periphery co-operate to define a gap for accommodating reciprocating

motion of the voice coil with the pole piece located internally with respect to the voice coil. The magnetic flux path assembly has a space defined between the pole piece, the inner wall of the magnet, and the pair of plates. The pole piece has a first passageway defined therein to permit fluid communication between the cavity and the space. The first plate has venting defined therein to permit fluid communication between the space and external ambient.

In an additional feature of that aspect of the invention, the venting includes at least one aperture defined in the first plate, the aperture being segregated from the opening. In another additional feature of that aspect of the invention, the periphery includes at least one sector of a circular arc. The sector has a radius measured from the axis and relief defined in the first plate. The relief extends away from the axis a distance greater than the radius of the sector, whereby the venting is at least partially defined by the relief. In still another additional feature of that aspect of the invention, the pole piece is a hollow cylinder having a base end mounted to the second plate, a distal end for location within the voice coil, and a wall extending between the ends. The base end is closed. The distal end has an opening defined therein. The wall has at least one port defined therein to permit fluid flow between the cavity and the space through the cylinder.

In yet another additional feature of that aspect of the invention, the pole piece is a post having a base end mounted to the second plate, a distal end for location within the voice coil, the distal end having an end face for location facing the cavity, and a wall extending between the ends, a portion of the wall bounding the space. The pole piece has a passageway defined therein. One end of the passageway terminates at a port defined in the end face of the distal end of the pole piece. The passageway has another end that terminates at a port defined in the portion of the wall bounding the space.

In a further additional feature of that aspect of the invention, the passageway is a straight bore formed in the pole piece on an inclined angle relative to the axis. In still a further alternative additional feature of that aspect of the invention, the passageway has a first bore extending inwardly from the one end of the passageway, and a second bore extending inwardly from the other end of the passageway to intersect the first bore. In yet a further alternative additional feature of that aspect of the invention, the passageway has a first bore extending inwardly from the one end of

the passageway, and a second bore extending inwardly from the other end of the passageway to intersect the first bore. In another additional feature of that additional feature, the second bore is a cross-bore extending fully through the pole-piece and having openings at either end thereof.

In still another additional feature of that aspect of the invention, the pole piece is a post having a base end mounted to the second plate; a distal end for location within the voice coil, the distal end having an end face for location facing the cavity; a medial portion narrower than the distal end; and a transition wall extending between the distal end and the medial portion. A portion of the transition wall bounds the space. The pole piece has a passageway defined in it. One end of the passageway terminates at a port defined in the end face of the distal end of the pole piece. The passageway has another end that terminates at a port defined in the portion of the transition wall bounding the space.

In yet another additional feature of that aspect of the invention, the transition wall is chosen from the set of transition walls consisting of an annular shoulder extending radially perpendicular to the axis and a truncated conically tapered section. The passage is a bore extending parallel to the axis. In still another additional feature of that aspect of the invention, the pole piece is a post having a base end mounted to the second plate, a distal end for location within the voice coil, the distal end having an end face for location facing the cavity, and a wall extending between the ends. A portion of the wall bounds the space; and distal end of the pole piece has a sidewall extending parallel to the axis. The sidewall has a radius measured from the axis, and at least one relief defined in the sidewall. The relief extends radially inwardly relative to the radius of the sidewall. The relief has a first end defined in the end face, and a second end giving onto the enclosed space, whereby air can be displaced along the relief between the cavity and the enclosed space.

In yet still another additional feature of that aspect of the invention, the relief in the distal end of the pole piece is a groove formed in the pole piece. The groove extends parallel to the axis. In a further additional feature of that aspect of the invention, the inner periphery of the first plate includes at least one sector of a circular arc. The sector has a radius measured from the axis. The inner periphery also includes at least one first plate relief defined in the first plate. The first plate relief

extends away from the axis a distance greater than the radius of the sector, whereby the venting is at least partially defined by the first plate relief.

In still a further additional feature of that aspect of the invention, the at least one first plate relief is an array of slots formed in the first plate in a symmetrical pattern relative to the axis. The at least one relief in the pole piece is an array of grooves formed in the pole piece. The number of slots is equal to the number of grooves, and the slots are aligned opposite the grooves.

In another aspect of the invention, there is a loudspeaker . It has a diaphragm assembly having a movable membrane, a dust cap mounted to the moveable membrane, a voice coil former, a voice coil formed thereon, and a cavity defined within the dust cap and the former. The loudspeaker also has a magnetic flux path assembly having a magnet. A flux land is connected in a magnetically permeable path to one pole of the magnet. A pole piece is connected in a magnetically permeable path to the other pole of the magnet. The diaphragm assembly has framing mounted to the magnetic flux path assembly and a suspension to permit the voice coil to reciprocate relative to the framing. The pole piece extends within at least a part of the voice coil. The flux land is located in spaced relationship from the pole piece to define a gap therebetween for accommodating reciprocation of the voice coil. The magnet develops a magnetic flux across the gap. The loudspeaker has an internal space defined between the pole piece, the magnet, and the flux land. The pole piece has a passageway defined therein having a port opening on the cavity and another port opening on the space. The flux land has venting let therethrough to permit fluid communication between the space and an external environment, whereby displacement of the dust cap urges fluid to be displaced between the cavity and the external environment along a fluid communication pathway that includes the passageway, the space, and the venting.

In an additional feature of that aspect of the invention, a magnetically permeable suspension fluid is introduced into the gap. In another additional feature of that aspect of the invention, the pole piece is a hollow post. The port opening on the cavity is an open end of the post. The port opening on the space is an aperture let through a sidewall of the post, and the post has a base end, opposite to the open end, the base end being closed. In still another additional feature of that aspect of the invention, the pole piece is a post having a groove let along a face thereof. The port

opening on the cavity is one end of the spline, and the port opening on the space is another part of the spline. In still yet another additional feature of that aspect of the invention, the pole piece is a post having a longitudinal axis parallel to the direction of reciprocation of the voice coil, and the spline is parallel to the axis.

In another aspect of the invention there is a loudspeaker. It has a diaphragm assembly having a movable membrane, a voice coil former, a voice coil formed thereon, and a cavity defined within the membrane and the former. It has a magnetic flux path assembly having a magnet, a flux land connected in a magnetically permeable path to one pole of the magnet, and a pole piece connected in a magnetically permeable path to the other pole of the magnet. The diaphragm assembly is mounted to the magnetic flux path assembly, and has a suspension to permit the voice coil to reciprocate relative to the magnetic flux path assembly. The pole piece has a post for extending within at least a part of the voice coil. The flux land is located in spaced relationship from the pole piece to define a gap therebetween for accommodating reciprocation of the voice coil, the magnet developing a magnetic flux field across the gap. The loudspeaker has an internal space defined between the pole piece, the magnet, and the flux land. The flux land has venting let therethrough to permit fluid communication between the space and an external environment.

<u>Brief Description of the Drawings</u>

Figure **1** is a cross sectional view of a loudspeaker assembly of conventional construction;

Figure **2** is a cross sectional view of an example of a loudspeaker assembly according to the principles of the present invention;

Figure **3** shows an alternative embodiment of loudspeaker assembly to the assembly of Figure **2** having an undercut pole piece;

Figure **4a**, shows another alternative to the loudspeaker of Figure **2**, in which air guides are mounted to direct air traversing the top plate;

Figure **4b**, shows an alternative vane arrangement to the loudspeaker of Figure **4a**;

Figure **4c** shows a plan view of a top-plate for the loudspeaker of Figure **4b**;

Figure **5a** shows a cross-section of an alternative to the loudspeaker of Figure **2** having an angular air communication passage;

Figure **5b** shows a cross-section of another alternative to the loudspeaker of Figure **2**, in which the pole piece is a tapered magnet having a vented cap;

Figure **6a** is a cross-section of an alternative to the loudspeaker of Figure **2** in which channels are provided adjacent to the voice coil;

Figure **6b** is a top view of the magnet assembly of the loudspeaker of Figure **6a**;

Figure **7** is a cross-section of a prior art closed cup tweeter;

Figure **8a** shows a tweeter with a pole-piece vented inside the magnet;

Figure **8b** shows an alternative embodiment of the loudspeaker of Figure **8a**.

Detailed Description of the Invention

The description which follows, and the embodiments described therein, are provided by way of illustration of an example, or examples of particular embodiments of the principles of the present invention. These examples are provided for the purposes of explanation, and not of limitation, of those principles and of the invention. In the description which follows, like parts are marked throughout the specification and the drawings with the same respective reference numerals. The drawings are not necessarily to scale and in some instances proportions may have been exaggerated in order more clearly to depict certain features of the invention. It will also be understood that although the loudspeakers described herein are shown in an upwardly oriented position, loudspeakers generally can be placed in horizontal, vertical , or tilted orientations. The terminology used when referring to top, back, front, inward, outward, upper or lower or other such term is not limited to a single orientation, but is given in the context of the illustrations.

Referring to Figure **1**, a low to mid-range frequency speaker, commonly referred to as a "woofer" is indicated generally as **20**, is shown in cross section. Loudspeaker **20** has a generally conical diaphragm member **22** that is mounted to a housing in the nature of a frame **24**, sometimes referred to as a "basket". The mounting of diaphragm member **22** is a resilient mounting having a lower, or inner suspension element in the nature of a damper, or spider **26** that extends from a narrower region of frame **24** to the throat **28** of diaphragm member **22**; and an upper, or outer, suspension member **30** in the nature of a surround **32**, of generally semicircular cross-section, that extends between the mouth **33** of conical diaphragm member **22** and the wider periphery **34** of the distal portion of frame **24**.

A round, cylindrical voice coil former, or bobbin **36**, depends from throat **28** of member **22**, to extend away from member **22**. The wall of bobbin **36** lies about an axis of linear reciprocation **40**, that is also the axis of revolution of conical diaphragm member **22**, and the central axis of loudspeaker **20** generally. Bobbin **36** is a thin walled, rigid circular cylinder, generally made of paper, KAPTON (T.M.), NOMEX (T.M.), aluminium, or other suitable material, upon which a voice coil **42** is wound. Voice coil **42** has a pair of leads **44** and **46** that extend along, and are glued to, the skin of conical diaphragm member **22**. A pair of flex, or tinsel, leads **48** and **50** carry input signals from terminals **52** and **54** to leads **46** and **48**.

The major portion of diaphragm member **22** is a truncated conical section, but is also includes a sealed membrane, in the nature of a dust cap **58** that extends across, and seals, the narrow, inner end of the conical section. Although member **22** is shown in the form of a truncated conical section, other shapes of diaphragm can be used, such as a spherical section, an ellipsoidal section, a pyramidal section, or a flat panel. It could also be a fully conical section extending to a point, without a dust cap membrane on a different arc or plane. In each case the diaphragm assembly is such that it closes the end of the voice coil bobbin.

A magnet assembly **60** has an annular magnet **62**, a back plate **64**, and an inner, or top plate **66**, formed in a sandwich that is concentric about axis **40**. A pole piece in the nature of a central, round, cylindrical post **70** extends inwardly from back plate **64** towards conical diaphragm member **22**. The outer face **72** of post **70** has a diameter sufficiently smaller than the inside diameter of bobbin **34** to permit voice coil **42** to reciprocate in a direction of reciprocation parallel to axis **40**. A pole piece, like post **70**, is also sometimes called a T-yoke. Pole pieces can be formed integrally with back plate **64**, either by machining from solid, by die casting, or by sintering of a compressed press powder metal part. Pole pieces can also be made by cold forming a cylindrical part to clinch on back plate **64**, or by welding, or a number of other fabricating processes. A typical pole piece, such as post **70**, has a central through bore **74**, that carries through an opening **76** in back plate **64** to give an airflow passage to external ambient. Most typically, top plate **66** is a flat, annular disc having one face bonded to magnet **62**. Top plate **66** has an inner face **76** having an inside diameter that is just large enough to let voice coil **42** travel without interference. Other forms of top plate can be made, whether plates of relatively great thickness, with a taper or

Not illustrated clearly

chamfer toward the inner edge, such as used in an over hung speaker, or relatively thin plates having a flange formed at their inner edge, such as used in an under-hung speaker.

Typically, back plate **66**, top plate **68**, and pole piece, or post **70**, are made of a materials of high magnetic permeability, such as a iron, steel or other ferrous alloy, or a nickel or cobalt alloy, or similar material. Most commonly they are made of iron or steel. When mated with magnet **62** they combine to form a magnetic flux path assembly, or magnetic circuit, that is complete but for a gap between the inner annular face **67** of top plate **68** and adjacent distal region **78** of post **70**. This gap, indicated as **80**, is sized to accommodate movement of voice coil **42**. One of the factors determining the overall efficiency of the speaker is the size of air gap **80**. Since the reluctance of the metal members is very much smaller than the reluctance of air gap **80**, it is desirable that air gap **80** be as small as possible without interfering with the free movement of voice coil **42**, allowing for manufacturing tolerances in the size of voice coil **42**, in the inside diameter of face **67**, and in the manufacture of the diaphragm assembly **22** generally.

Frame **24** is mounted to magnet assembly **60** by a footing **82**. When a time varying voltage is applied across terminals **52** and **54** voice coil **42** will move in the direction of axis **40** through the magnetic field prevailing across gap **80**. Inasmuch as bobbin **36** is rigid, any displacement of voice coil **42** will be matched by an equal translation of conical diaphragm member **22**. The limit of this motion will be determined by the time varying signal applied, and by the suspension. In due course the suspension will return the diaphragm assembly to its initial position.

A voice coil cavity, or diaphragm cavity **84** is defined as the open space within voice coil **42** bounded by the inner surface of the sealed central membrane of the diaphragm, that is, dust cap **58**, lying beyond the end face **85** of distal end **78** of the pole piece, post **70**. The outer cylindrical boundary of cavity **84** is the inner wall of bobbin **36**. The mean, or reference volume of cavity **84** is, in general, its volume at rest. Inasmuch as top plate **66** is annular, it lies entirely outside, that is, external to, bobbin **36**, voice coil **42**, and cavity **84**. The volume of cavity **84** is not constant over time, but varies with the displacement of dust cap **58**. Since dust cap **58** is, as noted, a sealed membrane, motion of bobbin **36** carrying voice coil **42**, and hence conical diaphragm member **22** results in the displacement of a volume of air along bore **74** of

post **70**. In operation at low volumes and moderate frequencies, the volumetric displacement is relatively small. However, typically at lower frequencies yielding large translations of voice coil **42**, the volume of air displaced may be significant relative to the overall volume of cavity **84**. This displacement of dust cap **58** results in an exchange of air through bore **74**. If bore **74** is closed, motion of voice coil **42** will tend to cause a compression (or expansion) effect since motion of dust cap **58** would tend to compress (or expand) the air in cavity **84**, and in bore **74**, however large its enclosed volume may be.

Another enclosed space **90** is defined within a round cylindrical inner surface **92** of annular magnet **62**, and the outer surface **94** of the pole piece, post **70**. This space is capped at either end by top plate **66** and backplate **64**. Since gap **80** is relatively small, rapid displacement of bobbin **36** and voice coil **42** will tend to compress (or expand) the air trapped in space **90**.

flux land

In terms of the magnetic flux path assembly described above, the magnet need not be the annular disc, but could be any of the elements, whether post **70** , top plate **66**, back plate **64**, or, as shown, magnet **62**, provided that there is a magnetic element of some kind in the magnetic circuit at some location. Similarly, the precise geometry of top plate **66** and post **70** can be varied. In general, there is a pole piece of some kind, a magnetic flux land adjacent to the pole piece, and a connecting member, whether made up of a single part of several parts joined together, that provides a relatively high magnetic permeability path between the flux land and the pole piece. The term high magnetic permeability is used in contrast to the magnetic permeability of the air gap, which is several orders of magnitude lower.

When low frequencies (bass) are applied to the woofer, the cone moves away from the magnet, or toward the magnet, depending on polarity. The frequency dictates how often per second the cone moves, and the magnitude of the voltage will determine the amplitude of the displacement against the restoring force of the suspension. When high power bass is applied, the woofer described above uses dust cap **58** to pump air through the vent, that is, the airflow passage, formed by bore **74** and the corresponding opening **76** in backplate **66**. The motion of dust cap **58** causes cool air to be sucked in, and warmed air to be blown out through the back of magnetic assembly **60**. This tends to provide some cooling for the pole piece.

Referring to Figure **2**, another loudspeaker is shown in cross-section, and indicated generally as **100**. It has a conical diaphragm member **102**, upper and lower suspension members **104** and **106**, terminals **108** and **110**, lead wires **112** and **114**, a dust cap **116**, a bobbin **118** and a voice coil **120**, arranged in generally the same fashion as noted above. Unless stated otherwise, these and other parts have generally the same construction and physical properties of the corresponding elements illustrated and described in the context of Figure **1**. The central axis of loudspeaker **100**, which is also the axis of reciprocation of voice coil **120**, is indicated as **121**.

An array of ventilation ports, or passages **122**, have been let through top plate **124**. Passages **122** can be formed in top plate **124** by being drilled, punched, pierced, cast, or formed by other conventional means. Although a single passage could be used, a symmetrical array of four passages on 90 degree centers about voice coil **120** is preferred. Passages **122** should have dimensions chosen to avoid, or discourage, whistling over the operational range of loudspeaker **100** generally.

Notably, back plate **126** does not have a central opening, but rather, the pole piece, that is, central post **128**, has a bore **130** that has a closed end **132** closed at back plate **126**. Vents, in the nature of lateral passages **134**, permit fluid communication between bore **130** and an annular chamber, or space **136** that lies about the exterior wall **137** of post **128**, and within the interior wall **139** of annular magnet **138** (which wall, **139** defines the eye of magnet **138**), and corresponds generally to space **90** described above. Also the lower portion **140** of basket, or frame **142** has perforations **144** such that the otherwise enclosed space, or chamber, **146** that lies between top plate **124** and lower suspension member **106** is vented to ambient. Although it is preferred to perforate lower portion **140** in this way, it would be possible to vent lower suspension member **106** to permit fluid communication to ambient as well.

Inasmuch as the clearance between bobbin **118** and post **128** is very small, displacement of voice coil **120**, and consequent displacement of the other members of the diaphragm assembly, will tend to force air to be displaced from (or to) cavity **148** under dust cap **116** (corresponding, generally, to cavity **84**), forcing some air to flow through passages **134** and, in turn, through passages **122** and perforations **144**. Large, low frequency displacements may tend to have the most pronounced effect in terms of air displacement.

In general use, the heating of voice coil **120** in use tends also to warm top plate **124** and post **128**. The exchange of air through the passages indicated as items **122**, **134**, and **144** tends to promote cooling of top plate **124** and post **128**. This also tends to promote cooling of voice coil **120**, with the result that loudspeaker **100** may tend to operate at a lower temperature than otherwise. Since voice coil **120** remains cooler, the increase in impedance of the coil due to heating may tend to be less than it might otherwise be, and the overall performance of the speaker may tend to be correspondingly improved. In effect, a relatively smaller loudspeaker may tend to be able to perform at a higher power level that would otherwise suggest the employment of a larger, possibly heavier and more expensive, loudspeaker unit.

The size and number of openings let through top plate **124** is neither so numerous nor so large as to detract significantly from thermal conduction in top plate **124**. Since the velocity of the air is greatest at the apertures, passages **122**, and since an exchange of hot air for cooler ambient air is promoted, the apertures may tend to be locations of relatively high convection heat transfer from top plate **124**. It is preferred that these apertures be smoothly radiused to discourage whistling.

Notably, loudspeaker **100** illustrated in cross-section in Figure **2** does not employ an aerodynamic vane or body in bore **74**, and as shown, does not employ complex channels of changing diameter or taper, although it could do. Although air communication passageways need not be straight, and could be formed at an angle, or on a taper, in dogleg form, or in a curved form and could have flared, rounded, or chamfered ends to reduce air noise, it is nonetheless preferred that the passages in post **70** be capable of fabrication by drilling or punching, or otherwise forming, as straight bores of constant diameter or slots of constant thickness, and that the openings in top plate **124** be formed by a similarly direct method to tend to reduce the cost and complexity of manufacture.

In the alternative embodiment of Figure **3**, parts that are the same as indicated in the context of the loudspeaker of Figure **2** are given the same identifying item numbers. The embodiment of loudspeaker of Figure **3**, indicated generally as **149**, differs from that of Figure **2** in that the pole piece, **150**, is a solid pillar having a narrow end **151** mounted to backplate **126**, and a widened distal end **152** about which voice coil **120** rides. The central axis is indicated as **154**. Pole piece **150** has a medial shoulder **156** such that distal end **152** has an overhang relative to narrow end **151**.

Medial shoulder 156 forms a transition wall between outer wall **155** of narrow end **151** and outerwall **157** of distal end **152**. Distal end **152** also has a distal end face **158** facing dust cap cavity. An array of straight through bores **160** each running parallel to axis **154** has been formed between face **158** and the annular face of shoulder **156**. The array can have any number found suitable to permit passage of air from cavity **162** beneath dust cap **116** and space **164** lying about pole piece **150** within magnet **136**, without noticeable whistling over the operational range of loudspeaker **148**.

In the alternative embodiment of Figure **4a**, parts that are the same as indicated in the context of the loudspeaker of Figure **2** are again given the same identifying item numbers. A loudspeaker is indicated generally as **170**. It differs from that of Figure **2** in air deflectors, in the nature of vanes **172**, **174** are shown mounted to each of passages **122** in top plate **124**. Vanes **172** and **174** are intended to promote enhanced heat transfer by convection from the end regions **176** and **178** of voice coil **120**. Vanes **172** and **174** could be formed as duct elbows, as shown, or as airfoils, or as deflector plates for imparting an inward radial component of momentum to the air displaced through top plate **124**, such that air discharged from either vane **172** or **174** will tend to have a component of velocity toward voice coil **120**, whether that velocity is directly radially inward with little or no tangential component, or whether, as is alternatively possible, there is a significant tangential component of velocity relative to voice coil **120** (that is, whether the vanes are angled to give a circumferential component of velocity as well). Similarly, the intake of vanes **172** and **174** is adjacent to regions **176** and **178** of voice coil **120**, to tend to encourage a higher rate of air exchange in those regions for encouraging improved heat transfer.

The inventor has noted that when loudspeaker elements are driven by too strong a signal, or by a clipped signal, at terminals **108** and **110** regions **176** and **178** tend to be the regions of voice coil **120** most prone to burn out prematurely. Vanes **172** and **174** may tend to enhance the tolerance, or the endurance, of regions **176** and **178** for operation under such conditions.

Figure **4b** shows an alternative loudspeaker **180**. It is similar to loudspeaker **170**, except insofar as it has a top plate **182** having an array of reliefs or notches **184** in the nature of roughly semi-circular cusps defined in plate **182** spaced about its inner edge **186**, rather than having holes formed through its main portion generally. As illustrated there are 7 notches on equal degree centers about axis **188**, notches **184**

being spaced apart by portions **185** of the closed inner periphery **187** of plate **182** that defines opening **183** in plate **182**. Portions **185** are sectors of a circular arc, concentric about axis **121** at a radius indicated as '**R**'. Plate **182** also has a circular outer periphery **188** that is concentric with portions **185** and pole piece, or post, **128**. Gap **191** is defined between portions **185** and post **128**. Notches **184** provide venting through plate **182** to permit displacement of air between enclosed space **136**, and external ambient **193**. Corresponding vane arrays **190** and **192** are mounted to extend from either side of top plate **182**, to channel the air displaced by the motion of dust cap **116** along the face of voice coil **120** in the angular intervals corresponding to the location of notches **184**. Figure **4c** is a plan view of top plate **182** showing the distribution of notches **184.**

In an alternative embodiment, the alternative, solid, undercut pole piece, **150** of Figure **3** could be used with loudspeaker **170** of Figure **4a** or **4b**.

In the alternative embodiment of loudspeaker **200** illustrated in Figure **5a**, pole piece **202** has an angled passageway **204**. An angled passageway, having one side **206** longer than the other **208**, may tend to discourage resonance phenomena.

In the alternative embodiment of Figure **5b**, a loudspeaker **210** is shown having a magnet **212** in the form of a pole piece, with a cap **214**, a top plate **216**, and support structure such as a linking member in the form of a ferro-magnetic cup **218**. Magnet **212** is mounted centrally on cup **218**, and is tapered from a relatively wide base **220** to a distal narrower end **222**. That is, magnet **212** is a truncated conical section. Cap **214** is a round disc that has passages **224** formed in it to permit air to be displaced between cavity **226** and internal space **228**. As before, top plate **216** has passages **230** to permit displacement of air between space **228** and external ambient, indicated generally as **232**, through openings in the basket or spider, or both, or through a similar passageway or groove, or space formed to permit airflow between the space indicated as **234** and ambient **232**.

In the alternative embodiment of Figures **6a** and **6b**, a loudspeaker **240** has a pole piece **242** and a top plate **244**. The space between them is indicated as **246**. Pole piece **242** has an array of four vertical channels **248** formed on ninety degree centers in its external face **250** parallel to central axis **252** of loudspeaker **240**. Pole piece **242** does not have a hollow center passage for conducting air in this example. Four semi-

circular notches, or rebates or reliefs, or bights **254** are punched in top plate **242** each being formed opposite one of channels **248**. Reciprocation of voice coil **120** will tend to cause air to be displaced in one direction in channels **248** parallel to axis **252**, and in the other direction through bights **254**. The critical gap dimension, indicated by Λ remains the distance between the remaining flux lands **256** of top plate **242** and the arcuate portions of pole piece **242** lying on its outer diameter. That is, space **246** is defined, on one side by the external side wall face **250** of the distal end region **241** of pole piece **242** opposite the opposed flux land **256** of the opposed member, top plate **244**. The other side of space **246** is defined by the closed inner peripheral wall **243**, or face, of top plate **244**. Peripheral wall **243** has portions, namely sectors **245**, that are sectors of a circular arc, all of sectors **245** being concentric about axis **252** and lying at a radius $\mathbf{R_2}$ therefrom. Peripheral wall **243** also has reliefs in the nature of bights **254** that extend outwardly of radius $\mathbf{R_2}$ a distance indicated as **M**.

It will be noted that vertical channels **248** of pole piece **242** are interspersed with arcuate sectors **247** about distal end region **241** of pole piece **242**. Sectors **247** are circular arcs concentric about axis **252**, and lie at a radius $\mathbf{R_3}$ therefrom. Channels **248** extend radially inward of radius $\mathbf{R_3}$ a distance indicated as $\mathbf{M_2}$.

Gap '**G**' is defined between sectors **247** and **245**. Sectors **247** and **245** channels **248** and bights **254** are all in the form of arrays arranged equally and symmetrically about planes intersecting axis **252**.

Neither bights **254** nor channels **248** need be formed in a semi-circular, or circular arc shape, but could be splines such as V-notches, keyways such as three-sided square notches, tapered notches, or some other form. Where such channels are used, the more-or-less semi-circular arcs shown are preferred. Channels **248** need not extend to the point at which the base **256** of pole piece **242**, but merely far enough to provide a clear passage past the most distant extremity of bobbin **118** from dust cap **116**, at its maximum excursion toward back plate **126**. Where used, it is preferred that channels **248** extend parallel to axis **252**. However they could be skewed or inclined with respect to axis **252**, such as to form a helical pathway or groove in the sidewall face of pole piece **242**.

In alternate embodiments, a pole piece, such as pole piece **242** could be used in conjunction with a top plate lacking bights **124**, but having passages such as

passages **132** of top plate **124**, or, alternatively, a top plate having notches, such as bights **124** could be used in conjunction with the pole piece of any of Figures **2**, **3**, **4a**, **4b**, **5a** or **5b**.

It is not necessary that the opening in the top plate have a round, that is, circular form, or that it be a closed periphery, although this is preferred. The shape of the opening or slot in the top plate does correspond to the shape of the pole piece in cross-section, and to the shape of the voice coil in cross section, to define the gap width, such as the width **'G'** described above. The general shape of the opening, whether in the context of Figure **2**, **3**, **4a**, **4b**, **5a** or **5b**, could be round, triangular, oval, elliptical, square, hexagonal, star shaped, or some other arbitrary shape such as may be chosen. Similarly, the sectors of the circular arcs need not be concentric about a common axis, and need not be circular sectors.

Figure **7** shows a tweeter **300** of conventional design with a diaphragm assembly **302** having a dome membrane **304**, a resilient suspension **306** surrounding the dome, a pair of leads **308**, **310** leading, respectively to terminals **312** and **314**, a bobbin **316** and a voice coil **318** formed on bobbin **316**. Tweeter **300** also has a magnetic assembly **320** having a top plate **322**, an annular magnet **324**, and a backplate **326**. The central axis of tweeter **300** is indicated as **330**. Top plate **322** is annular, and has an inner, chamfered edge and a flux land **332** opposite the distal end **334** of pole piece **336** mounted to backplate **326**. Pole piece **336** is hollow, having a central bore **338** extending from a cavity **340** under dust cap, or dome membrane **304** fully through back plate **326**.

Notably, the back of tweeter **300** is closed off by a backshell, or cup, **342**. The internal volume **344** of cup **342** is large relative to the volume of cavity **340**, such that air pressure variations under membrane **304** do not interfere excessively with operation of tweeter **300** generally. In practice volume **344** of cup **342** tends to be chosen by the speaker designer to provide an optimum operating resonance condition at the design point of the tweeter, and to provide acceptable performance over the tweeter operating range to either side of the design point.

Also shown in Figure **7** is a space **346** defined between the circular inner face **348** of annular magnet **324**, the outer face **349** of pole piece **336**, top plate **322**, and backplate **326**. This space, or chamber, or enclosed volume, is analogous to space **90**

described above. In tweeter **300** shown in Figure **7**, a face plate **350** mounts diaphragm assembly **302** to magnetic assembly **320**. There is neither venting through top plate **322** nor through back plate **326** in communication with space **346**.

Figure **8a** shows a tweeter **380**. Again, common parts with tweeter **300** are indicated by common item numbers. Tweeter **380** does not have a central bore, and backplate **382** is imperforate. That is, backplate **382** does not have a communicating passageway for permitting air to enter or exit tweeter **380**. Tweeter **380** has a pole piece **384** that has a passage **386** defined in it extending between distal face **388** of the distal end portion of pole piece **384** and a port **390** located on the trunk, or circular sidewall **392** of pole piece **384** to give onto space **346**. As shown, displacement of dome membrane **304** parallel to axis **330** will tend to compress or expand the air not only in cavity **340** under dust cap dome membrane **304**, but also the volume of air entrapped in space **346**. The elimination of cup **342** tends to reduce the depth, and the overall enclosure envelope, of tweeter **380** as compared to tweeter **300**. The inclination of passage **386** and the inequality of length of its sides **394** and **396** tends to give a different, and preferred, frequency response characteristic to that obtained with the passage shown in Figure 7. Passage **386** of Figure **9a** need not be round, or straight, but could vary in shape, angle, aspect ratio, or cross-sectional area.

Figure **8b** shows a cross-section of a tweeter **400**. In this embodiment a pole piece **402** is provided having an obstructed, or capped end **404** at backplate **406**, and a well, in the nature of a blind bore **408** extending inwardly from its distal end **410**. A cross bore **412**, shown as having a smaller diameter, is formed, typically by drilling, across the trunk **414** of pole piece **402** to intersect bore **408** at its profound end. Cross-bore **412** is open at either end to space annular **416** such that a path of fluid communication is established between space **416** and cavity **418** under dust cap dome membrane **420**. In this way, reciprocation of membrane **420** will again cause compression and expansion not only of the volume of cavity **418** but also of space **416**. Again, tweeter **400**, like tweeter **380**, does not employ a backshell, or cup such as cup **342**.

Various embodiments of the invention have now been described in detail. Since changes in and or additions to the above-described best mode may be made without departing from the nature, spirit or scope of the invention, the invention is not to be limited to those details, but only by the appended claims.